Summerfallow Reduction on the Prairies and Mitigation of Greenhouse Gas Emissions

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Abstract

Previous research has shown that in relatively moist areas of Saskatchewan the use of crop rotations that exclude summerfallow is desirable from the perspectives of C sequestration and reduced greenhouse gas (GHG) emissions as well as from the soil quality perspective. In this study, the Canadian Economic and Emissions Model of Agriculture (CEEMA) was used to evaluate, based on a systems approach, the total reduction in greenhouse gas emissions associated with reduced summerfallow. Results show that analyses based only on a partial set of information – reduction in the area of summerfallow – overestimate the mitigation effect. Since the land that is taken out of summerfallow does not remain idle, but is used in crop or forage production, the GHG emissions of the alternative land use must also be considered. Crop production requires farm inputs, such as N fertilizers, which contribute to the total emissions of greenhouse gases from agriculture. The conversion of summerfallow to crop production, based on a reduction in summerfallow area by 50%, decreased GHG emissions by one megatonne only if the C sequestration benefits of reduced summerfallow are counted as an offset. If the sink is not counted, the GHG emissions increased as land shifted from summerfallow to crop production. However, a considerable degree of uncertainty exists, and more research is needed on this aspect of mitigation.

Introduction

In 1997, the Canadian government made a commitment in the Kyoto Protocol to reduce national GHG emissions to 6% below 1990 levels by 2008 to 2012. Unlike most other sectors of the Canadian economy, such as the manufacturing, transportation, or energy sectors in which carbon dioxide (CO_2)from the combustion of fossil fuels is the major GHG, in agriculture nitrous oxide (N_2O) and methane (CH_4) are the dominant GHG. Agriculture is a biologically based system in which the magnitude and sources of GHG emissions are determined by the extent to which crop production has changed the magnitude and function of the C and N cycles. For agriculture, GHG mitigation is not just a matter of achieving efficiencies in fossil fuel use, but must also include improved management of C and N in crop and livestock production.

The federal government established, among others, two tables related to agriculture -- the Agriculture and Agri-Food Table, and the Sinks Table, to begin the process of development of a national strategy for the reduction of GHG emissions. Through this process, it was recognized that C sequestration in agricultural soils (soil sinks) was among the mitigation strategies that offered significant emission reduction potential for agriculture. Carbon sequestration is associated with farming practices that increase the amount of crop biomass returned to the soil and reduce the rate of organic matter loss from the soil. Soils function as sinks when the organic C in crop biomass is transformed through soil microbial processes into stable soil organic matter. Whereas most GHG mitigation strategies are based on reducing emissions and sources, soils sinks represent a net removal of CO_2 from the atmosphere.

Under the current Kyoto Protocol agreement, removals of CO_2 in agricultural soils are not recognized as a C sink. The only landuses to which both emissions and removals of CO_2 are attributed are reforestation, afforestation and deforestation (RAD). The Protocol does allow for future negotiated additions of other landuses and human activities with sink potential, such as agriculture and soils, however, the inclusion of agricultural soils will not likely occur before the sixth meeting of the Conference of the Parties in late 2000, at the earliest.

This report provides estimates of the "net" GHG emissions (i.e., sources minus sinks) that result from a reduction in the frequency of summerfallow in Prairie agriculture, compared to the business-as-usual projections for 2010. The work was done as part of a larger modeling exercise (see Junkins, et al., 2000).

The Canadian Economic and Emissions Model for Agriculture (CEEMA)

The analyses reported in this paper were done using the Canadian Economic and Emissions Model of Agriculture (CEEMA), as reported by Kulshreshtha et al. (1999). CEEMA is a linkage of the Canadian Regional Agriculture Model (CRAM) with a GHG emissions submodel. CRAM is a model of the Canadian agriculture sector that simulates production, marketing and transportation of major crop and livestock commodities within constraints of available land resources and the final demand for the products. GHG emission estimates were based on emission coefficients, which represent the amount of GHG produced per unit of output or level of activity. The coefficients were developed following the IPCC guidelines (Houghton et al, 1996). The CEEMA is not a GHG inventory tool. However, it systematically links information about the range and magnitude of agricultural activities in Canada with the available scientific data (empirical and theoretical) on GHG sources or sinks from crop production activities. The model is disaggregate at the provincial level and the crop district level on the Prairies.

Baseline GHG emissions from Canadian agriculture were estimated for the 1990 agriculture as predicted by CRAM. Predictions of GHG emissions for 2010 were based on the level of Canadian agricultural activities forecast in Agriculture and Agri-Food Canada's (AAFC) medium term policy baseline (AAFC, 1999). The agricultural emissions from reductions in summerfallow frequency were estimated by changing model parameters to simulate less fallow land.

Emission Activities in the Model.

CEEMA estimates direct and indirect sources of emissions from crop and livestock production. The direct sources of emissions are N_2O from crop residues, N fertilizer, N-fixing crops, the manure of grazing animals, and manure in storage, CO_2 from soil organic matter, and CH_4 from ruminant animals and manure. Indirect sources of emissions include the atmospheric deposition of N_2O from N fertilizers and manure, leached N fertilizer and animal manure, and human sewage, and CH_4 from organic soils (Hisotosols) and waterlogged lands. The uptake of CH_4 by agricultural soils, which functions as a removal, was also estimated.

Sequestration coefficients.

The C sink was estimated for agricultural soils as the rate of change in soil organic C for particular cropping systems. Although it is generally agreed that soil C increases when soil-conserving practices such as zero tillage and reduced summerfallow are adopted, there is uncertainty and disagreement about the rate at which the increase occurs. Some of the uncertainty arises because it is difficult to measure short-term changes (years rather than decades) in soil C, given that annual changes in organic C are very small in relation to the total amount of soil organic C, particularly in Prairie soils. The total organic C content of soils ranges from about 100 T ha^{-1} in the Black soil zone to about 60 T ha^{-1} hectare in the Brown soil zone (Anderson, 1995). In contrast, estimated annual C additions associated with the shift from conventional farming to zero tillage systems range from about 0.1 to 0.5 T C ha^{-1} y^{-1} for ~20 years (Table 1). Such small incremental changes are difficult to detect against the large background of total soil C.

Measurement and detection of changes in soil organic C is further complicated by its spatial variability within the landscape. Soil organic C content can vary by several tonnes per hectare from the top of a knoll to the depressions and, even under best management practices, soils with a low water storage capacity or poor fertility produce less biomass C and store less organic C than more productive soils. Unless the spatial variability is understood and accounted for, systematic changes or trends in soil C content resulting from changes in farming practices cannot be detected.

Despite the difficulties in measurement and prediction of changes in soil C content, the general conditions under which it is possible to sequester C and approximate rates of change are known (Bruce et al., 1999). Based on available empirical and theoretical information, two sets of C sequestration coefficients were developed for CEEMA to represent a range of cropping systems and soil conserving land management strategies (Table 1). One set of coefficients was developed by Desjardins et al. (2000) using the Century model (Century coefficients) and the second set, referred to as the Expert Opinion coefficients, was developed by McConkey et al. (1999) from empirical data. The range in the coefficient values indicates, to some extent, the level of uncertainty in the rate of soil C change in response to management practices. More information on the sequestration coefficients is given in Boehm et al, 2000.

The C sequestration coefficients for reduced summerfallow on the Prairies were based on the change in cropping frequency over the time of the analysis. They reflect the rate of increase in soil C associated with a reduction in the frequency of summerfallow in crop rotation. Table 1 shows the SF coefficient values the cropping frequencies of the 2010 BAU scenario, which were calculated from the change in cropping frequency between the 1990 baseline and 2010 BAU scenarios.

Table 1. The Expert Opinion (EO) (McConkey et al., 1999) and Century (C) model (Smith et al., 1999) C sequestration coefficients (t CO_2 ha^{-1} yr^{-1}) for the adoption of soil-conserving farming systems.

Farming System	SOIL ZONE Brown EO	Brown C	Dark Brown EO	Dark Brown C	Black EO	Black C	Non-Prairie EO	Non-Prairie C
Zero tillage	0.73	0.22	0.73	0.44	1.34	0.54	0.76[1]	0.54
Minimum tillage		0.08		0.16		0.26		0.26
Reduce SF[2]	0.15	0.13	0.16	0.29	0.08	0.20		
Crop to forage	0.73		1.78	0.94	3.23	2.44	3.23	2.44
Permanent cover	2.93	0.88	2.93	1.15	2.93	3.3	2.93	3.3

[1] from Century output, June 1999
[2] based on cropping frequency and are calculated for each scenario. The values shown are for the 2010 BAU scenario.

Baseline Business-as-usual Scenarios

The GHG sources and sinks associated with agricultural activities were estimated for 1990 and 2010 business-as-usual (BAU). Agricultural soils are not recognized as a CO_2 sink in the Kyoto Protocol, and since there is no guarantee that soil sinks will ever be included, GHG emissions for each scenario were estimated according to the current IPCC guidelines (i.e., without sinks) with the sink potential was separately estimated. Net GHG emissions, the sink minus IPPC total emissions, indicate how the inclusion of sinks would affect mitigation potential of the scenarios.

1990 Baseline Emissions. In 1990, total agriculture land in Canada was about 62.2 million hectares, of which 57% was in cropland and summerfallow with the balance in hayland and pasture. There were about 4 million beef cattle, 1.3 million dairy cows, 10.5 million hogs and 3.5 million poultry. Tillage practices in 1990 were linearly extrapolated from the trends in adoption of zero and minimum tillage between 1991 and 1996, shown in Table 2.

Table 2. Change in tillage practices (%) on the Prairies between 1991 and 1996.

Land Management	Manitoba	Saskatchewan	Alberta
Minimum tillage	-9.9	31.9	29.0
Conventional tillage	-10.4	-27.0	-25.4
Zero tillage	70.4	116.9	215.3

Source: Kulshreshtha et al., 1998

Total GHG emissions from Canadian agricultural crop production activities, based on the IPCC inventory guidelines, were 57.6 MT CO_2 –E (Table 3). The largest proportion of emissions were CH_4 and N_2O from livestock production, although CO_2 emissions from soil organic matter decomposition accounted for 6 MT of CO_2 emissions. The 1990 sink estimate, 10 kT C in Canadian agricultural soils was taken from the Canadian 1990 GHG inventory (Environment Canada, 1997).

GHG emissions, on a provincial basis, occurred in proportion to the area of cropped land and the size of the animal herd in each province. Alberta and Saskatchewan, with the largest area of cropland and livestock numbers, produce the most agricultural emissions. Emissions from Ontario are also comparatively high, reflecting the large number of livestock in that province.

Canada's target for reduction of GHG emissions is 6% below 1990 levels. If the same reduction target were applied to the agriculture sector, allowable emissions between 2008 and 2012 would be 6% less than 57.5 MT, or 54.1 MT CO_2 -E (Table 3).

<u>2010 Business-as-usual Scenario</u>. Under the 2010 BAU scenario, agricultural land base was assumed to remain constant at 1996 census levels. Crop and hay yields were increased on trend and nitrogen fertilizer use in Western Canada was increased by 25% over the 1996 level. The area of summerfallow was reduced to 5 million hectares whereas zero tillage was increased by 25% of 1996. Compared to 1996, cattle production was increased by 10% in the west and 2% in the east and hog production was increased by 31% in the west and 8% in the east.

Canadian GHG emissions from agriculture increased by ~12% between 1990 (57.6 MT CO_2-E) and 2010 (65 Mt CO_2-E) (Table 3). With business-as-usual, 2010 emissions exceed the Kyoto target of 54 Mt CO_2-E by 20%, mainly due to greater N_2O and CH_4 emissions from livestock production and N fertilizer use on the Prairies. The increase in emissions was offset partially by a reduction in CO_2 emissions from soils. Carbon dioxide emissions from soil decreased from 6033 kT CO_2 in 1990 to between 537 and 563 kT CO_2 in 2010, largely due to the adoption of zero and minimum tillage practices on the Prairies.

C sequestration in Canadian agricultural soils, based on the Century coefficients, rose from 10 kT CO_2-E in 1990 to 5826 kT CO_2-E in 2010 (Table 4). If the sequestered C was considered a sink and used to offset total emissions, the net increase in GHG production between 1990 (57.6 Mt CO_2-E) and 2010 (59.1 Mt CO_2-E) would be reduced from 12% to 3%, which is 9% above the Kyoto target (Table 3).

Table 4. Rate of adoption of reduced summerfallow (Source: B. MacGregor, EPAD, Policy Branch, AAFC).

Applicable Region	Soil zone	Adoption Rate (M ha) 2010 BAU	SF Scenario	% change
Prairies and B.C. Peace River	Black/Gray soils	1.4	0.7	-50
	Dark Brown	1.4	0.8	-40
	Brown	2.7	1.5	-30
	Prairies	4.9	3.0	-38

Table 3. GHG emissions for Canadian agriculture under 1990 baseline, 2010 business-as-usual (BAU) and reduced Summerfallow frequency (2010 ↓SF) scenarios, as total emissions (kT) and as a proportion of the Kyoto Target (% of target). Scenario 1 estimates emissions for a 50% reduction in SF area. Scenario 2 estimates emissions for a 50% reduction in SF area if soils under SF are assumed to emit 1 kg N_2O ha^{-1} y-1.

Scenario	**Century Coefficients**						**Expert Opinion Coefficients**					
	CO_2	**CH_4**	**N_2O**	**CO_2E**	**Sink**	**Net[1]**	**CO_2**	**CH_4**	**N_2O**	**CO_2E**	**Sink**	**Net**
	GHG Emissions (kT y^{-1}) - Scenario 1											
1990 baseline	6,033	994	99	57,574	-10	57,564	6,033	994	99	57,574	-10	57,564
% of target				106		106				106		106
2010 BAU	563	1,138	131	64,962	-5,826	59,136	537	1,138	131	64,936	-6,280	58,656
% of target				120		109				120		108
2010 ↓ SF	534	1,147	135	66,597	-6,120	60,477	397	1,147	135	66,459	-9,504	56,955
% of target				123		112				123		105
	GHG Emissions (kT y^{-1}) - Scenario 2											
1990 baseline	6,033	994	107	60,005	-10	59,995	6,033	994	107	60,005	-10	59,995
% of target				106		106				106		106
2010 BAU	563	1,138	136	66,496	-5826	60,670	537	1,138	136	66470	-6,280	60,644
% of target				118		108				118		108
2010 ↓ SF	534	1,147	138	67,556	-6120	61,436	397	1,147	138	67,418	-9,504	57,914
% of target				120		109				120		103

[1] CO_2-E minus Sink

The Expert Opinion coefficients predict a greater rate of sequestration than the Century coefficients, particularly for zero tillage (Table 1). As a result, these coefficients predicted a slightly larger soil sink (6280 kT CO_2-E) than the Century coefficients (Table 3), equal to about 10% of total emissions. On a net emissions basis, the gap between 2010 BAU and the Kyoto target would be 8%.

Saskatchewan and Alberta account for 51% of the GHG emissions from agriculture in the 2010 BAU scenario. However, the Prairie provinces also accounted for the largest sequestration potential. For example, in Saskatchewan, where zero tillage has increased and summer fallow has decreased since 1990, the C sink was estimated to be 30% of emissions.

The 2010 BAU scenario demonstrates the importance to agriculture of the inclusion of sinks in the Kyoto protocol. If sinks are included and the adoption of zero tillage, minimum tillage and reduced summerfallow continue on trend, Canadian agricultural emissions would be reduced by about 6 MT CO_2-E y^{-1} compared to the IPCC-based estimate.

Reduced Summerfallow Scenarios

The rate of loss of soil organic C tends to be higher under summerfallow conditions, particularly tillage fallow which uses cultivation to control weed growth, than under continuous-cropping. During the summerfallow year, there is no crop or plant production, so biomass additions to the soil are low. Compared to cropped soils, the fallow soil environment tends to be warm and moist, which promotes a high rate of organic C mineralization and loss as CO_2. A reduction in the frequency of summerfallow, or its elimination from the crop rotation, reduces the mineralization rate and increases the amount of crop residue returned to the soil, which combine to enhance C storage and soil sink potential.

Summerfallow is a common, but declining, practice in the Prairie region. Relative to the 2010 BAU, for this scenario the rate of summerfallow was reduced by a further 50% in the Black soil zone and 30% in the Brown soil zone, for an average reduction of 38% for the Prairies (Table 4).

Systematic changes in land use and production resulted from the decline in summerfallow acreage. Compared to the 2010 BAU scenario, as the area of summerfallow declined, the amount of crop produced on stubble increased. Although yields on stubble were lower than on fallow, total grain production increased in proportion to the increase in seeded acres, as did the use of crop production inputs, such as fertilizers and pesticides. Because there was a slight increase in hayland and feed grains, livestock production slightly increased (2%) and shifted to western Canada.

Two versions of the reduced summerfallow scenario were developed:

<u>Scenario 1.</u> The original scenario assumed that N_2O emissions were associated with crop residue decomposition and fertilizer application, and N_2O emissions from the denitrification of soil N were similar for summerfallow and cropped soils.

Scenario 2. Based on the available empirical data, Scenario 2 reflects the effects of reduced summerfallow if it is assumed that summerfallow soils emit N_2O. It has been suggested that under the moist conditions of summerfallow, soil losses of N_2O would be greater than under cropped conditions. Aulakh et al. (1982) measured greater N_2O emissions from fallow than fertilized soils during the growing season on the Prairies, and although Lemke et al. (1999) did not measure consistently higher emissions from fallow soils, they reported that losses from fallow were often higher during the spring thaw. Although the empirical data were not conclusive, after consultations with Lemke (SPARC) and Burton (U. of M.), a coefficient 1 kg N_2O ha^{-1} of summerfallow land was used in Scenario 2.

Carbon sequestration coefficients**.** The C sequestration coefficients for reduced summerfallow frequency are given in Table 1. The Century coefficients were derived using the Century model to predict changes in soil organic C content in response to a reduction in the frequency of summerfallow over a ten-year period. The change in soil C stocks as summerfallow frequency declined was estimated for cropping frequencies characteristic of the soil zones. The coefficients reflect the average increase in soil C as summerfallow frequency declines.

The Expert Opinion coefficients reflect the rate at which C is sequestered as summerfallow frequency declines. The coefficients were calculated from the change in cropping frequency over the period of the simulation. The greater the reduction in summerfallow over time, the larger the sequestration potential. As a consequence, in the Black soil zone where summerfallow is not a common practice, the change in crop frequency over time and, thus the amount of C sequestered from the elimination of summerfallow was relatively small. Cropping frequency for calculation of the coefficients was assumed to increase from 86% in 1990 to 91% in 2010 for the BAU scenario and to 95% for the reduced SF scenario. In contrast, in the Brown soil zone where summerfallow is a more common practice, cropping frequency was assumed to increase from 59% in 1990 to 67% for 2010 BAU and to 77% for the reduced summerfallow scenario. The Expert Opinion coefficients are applied to all of the cropped land in the appropriate soil zone to represent the effect of a reduced frequency, rather than the elimination, of summerfallow.

Scenario 1 -- GHG Emissions. Total GHG emissions rose by 3% under the reduced summerfallow scenario compared to 2010 BAU (Table 3). The increase resulted mainly from an increase in N fertilizer and N_2O emissions and livestock production and CH_4 emissions as crop land increased and summerfallow declined. Total C sequestration based on the Century coefficients was 6.1 MT CO_2-E compared to 5.8 MT CO_2-E for 2010 BAU, and net GHG emissions were 60.5 MT CO_2-E, an increase of 3% of 2010 BAU (Table 3).

The sink estimated with the Expert Opinion coefficients, 9.5 MT, was large enough to offset the increase in N_2O and CH_4 emissions, such that the net emissions (57 MT) were reduced relative to 2010 BAU (58.7 MT) (Table 3).

<u>Scenario 2 -- GHG Emissions</u>. If it is assumed that summerfallow soils emit 1 kg N_2O ha^{-1} y^{-1}, total emissions for the 1990 baseline, 2010 BAU and reduced summerfallow scenarios increase in proportion to the amount of summerfallow land in each scenario (Table 3). As a consequence of higher 1990 baseline emissions, the Kyoto target for this scenario was 56,405 kT CO_2-E.

Compared to 2010 BAU, Scenario 2 GHG emissions increased by 2%, reflecting the balance between an increase in N fertilizer use and N_2O emissions and decreased N_2O emissions as fallow soils are converted to cropped soils. Net emissions based on the Century coefficients increased by 1% above the 2010 BAU, whereas the Expert Opinion coefficients estimated a decline in net emissions by 5% below the 2010 BAU (57.9 versus 60.6 MT CO_2-E) (Table 3).

Reduced Summerfallow and GHG Mitigation

GHG emissions from reduced summerfallow frequency reflect both the increase in C sequestration that occurs as summerfallow is eliminated, the increase in GHG emissions that result when summerfallow is replaced by crop, and for scenario 2, the added benefit of a reduction in emissions of 1 kg N_2O ha^{-1} y^{-1}. As summerfallow acreage declined, more land was allocated to crop production, which increased the use of N fertilizer and therefore increased N_2O emissions. Since N_2O has 310 times the warming potential of CO_2, only a small increase in N_2O is required to offset the removal of CO_2 in soils.

Since the net reduction in GHG emissions for reduced summerfallow is determined by the balance between N_2O emissions from crop production and C sequestration from a reduction in summerfallow frequency, it should be noted that the N_2O emission coefficient for N fertilizer was the IPCC value of 0.0125 (Houghton et al., 1996) which may be an overestimate for Canadian conditions. Further research on the rate of N_2O emissions from N fertilizer use under Canadian conditions and from summerfallowed soils are required before this scenario can be conclusively analyzed.

The baseline and reduced summerfallow scenarios illustrate the potential for GHG mitigation in agriculture if C sequestration in agricultural soils is permitted within the Kyoto Protocol and IPCC inventory procedures. Agriculture differs from most other sectors of the Canadian economy in that N_2O and CH_4 emissions are larger than CO_2 emissions for most activities and C sequestration in agricultural soils could offset a significant proportion of emissions. Most sectors, such as the transportation, industrial, or energy sectors, produce mainly emissions of CO_2 from the combustion of fossil fuels. Mitigation in those sectors is focussed on a reduction in fossil fuel use and increased fuel-use efficiencies. A national GHG reduction strategy for Canada that involved mainly reducing emissions from fossil fuels would not necessarily reduce GHG emissions from agriculture. The CEEMA scenarios and analysis indicate the magnitude of N_2O and CH_4 emissions from agriculture and indicate the importance of sinks in achieving significant reductions in emissions from agriculture in the short and medium-term (i.e., by 2008-2012, the first commitment period of the Kyoto Protocol).

The scenarios also demonstrate the large uncertainty in estimates of GHG emissions from agricultural activities at the national level. Uncertainty is associated with the coefficient values, adoption rates, and systems readjustments that result from the adoption of mitigation practices. Sources and sinks of GHG from agricultural activities derive from spatially and temporally variable processes, for which it is not possible to develop simple coefficients that do not embody significant uncertainty. However, research could result in a better understanding of emission parameters under Canadian conditions, especially for N_2O emissions from fertilizer, N-fixing plants and soils.

More research is also required to understand the relationship between adoption of mitigative practices and policy. Although much of the criticism of these analyses has focussed on the large uncertainty associated with emissions coefficients, perhaps even less is known about adoption rates and producer behavior between now and 2010. There is little value in the development of more precise emission coefficients if the same degree of precision cannot be achieved in prediction of producer behavior.

The CEEMA modeling exercise, despite the large degree of uncertainty, was useful as a demonstration of the importance of adopting a whole system approach for the estimation of the GHG emission reduction potential of mitigative strategies, and to indicate the importance of sinks in achieving real emissions reductions.

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